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COMPLETE SPECIFICATION

DRAWINGS ATTACHED

Casting Complex Structures with Foamed Metal Core and Solid Skin

We, LOR CORPORATION, of Enid, Oklahoma, United States of America, a Corporation organised under the laws of the United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the casting of complex structures with foam metal cores, and particularly to the manufacture, in one single casting operation, of an object of complex shape having a continuous skin of substantially unbroken metal.

The Specification of Patent No. 729,339 describes and claims a cellular metal body having closed bubble-like cells containing a gas. A method of producing such a body comprises effecting wetting of a heat decomposable gas-forming solid by a molten metal, and decomposing by means of heat said wetted solid immersed in the molten metal.

In particular, prior to the present discovery, no method has been known to produce, in a single operation, a complex shape or form such as a chair or a table, or a saddle, or a building-or machine-part or a part for an automobile or air-plane or the like involving several bends or compound curvatures, having a continuous dense metal skin, and yet having a cellular light weight core of the same metal.

We have now made the surprising discovery, that it is possible to prepare such an article of complex shape in a single operation, by casting a potentially foamable metal mixture under certain conditions and in certain temperature time relationships with the mould temperature. This depends on the fact that the metal in the foamable mixture will just sufficiently solidify on contact with a colder inner surface of a mould into which it is poured, so that a solid, substantially non-porous outer skin is formed.

Based on this discovery, and in contradistinction to the method indicated above, the present invention provides the method of casting in one operation, a metal article which may be of complex shape, having a continuous substantially non-porous metal skin and a low density core of the same metal which consists of a large number of closed cells extending through most of the interior of the core, which method comprises the steps of intensively intermixing a molten metal and a substance capable of forming a gas at the melting point of said metal, introducing said mixture substantially before foaming has taken place into a mould, the inner surface of which has a temperature sufficiently low to cause solidification of said metal as a substantially non-porous skin adjacent the inner mould surface and causing to be abstracted or abstracting heat from said mould at such a rate that the said skin is not remelted or foamed.

This present method renders possible such surprising and unexpectable results as for example being able to cast a chair of aluminium having an apparent specific gravity of only 0.4 and yet being cast in one single operation. The resultant material and cost saving are important features of this invention.

The formation of a foam metal casting of uniform density and of smooth non-cellular thin outer surface is best provided by abstracting heat from a mould charged with molten foamable metal at a rate which substantially balances the rate at which heat is transferred to the mould by the metal during the casting process. In many

instances molten metal foaming mixtures are not sufficiently endothermic or self-cooling to reduce the temperature of a casting rapidly enough to freeze the foaming mixture when the desired density of metal foam in the mould is reached with the result that the casting over-expands causing the thickness of the cellular walls to be reduced until the walls rupture and the foam collapses. Conversely, when the temperature differential between the molten metal and the mould is sufficient to prevent over-expansion of the metal in the mould, an undesirably thick layer of dense substantially unfoamed metal may freeze on the casting. To maintain the inner surface of the mould at a desirable and relatively constant temperature while foamable metal is expanding in the mould, heat exchange media is preferably provided in contact with the outer surface of the mould. Mould temperatures below the liquidus or melting point of the metal being cast are desirable, and temperatures within a few degrees of the solidus temperature of an alloy are often optimum. To insure that the expansion of foamable metal in the mould does not progress to an undesired degree or that large cells are not formed in the casting, the mould may be quenched in water or in an air blast to cool the casting and freeze the cellular structure after foaming has progressed for a suitable time. Quenching may be operably employed with pre-heated moulds if desired in the absence of mould heat control means.

In order to enable the invention to be more readily understood, reference will now be made to the accompanying drawings, which illustrate diagrammatically and by way of example some embodiments thereof, and in which:—

Fig. 1 is a section through a mould and pouring apparatus illustrating the manufacture in one operation of a table made of foamed metal,

Fig. 2 is a section through the resulting table, and

Fig. 3 is a section through another mould and pouring apparatus.

Referring now to Fig. 1, metal 1 is molten in a tiltable furnace 2, and then supplied by pouring over a weir-spout 3 to a mixing vessel 4, where it is intermixed by an impeller 5 driven by a motor 6 with a foaming agent 7, supplied as a rod or as a powder contained within a tube by means of a controlling and feeding device 8. From the mixing vessel, the mixture of now foamable material is caused to move or is moved before it has time to develop an appreciable amount of foam over a lip 9 into the cavity 10 of a mould 11 which in this case is a mould of a seven-person round dining-room table, in an upside-down position. The mould is maintained at the preferred temperature either by virtue of the balanced thermal conductivity properties of the mould material, or by an external heating means which for simplicity is not shown. This is particularly desirable when thin metal moulds are employed.

Figure 2 show the structure of the table thus cast, in a sectional view. Along the surface of the table is a zone, 12, which is characterized by the absence of bubbles. This is a firm, substantially non-porous metal skin. The thickness of this skin can be varied within considerable limits dependent on the details of the operation, as further described in the examples, but generally it will be between 0.4 and 10 millimetres. Just inside this dense zone is a layer 13 of relatively small and dense bubbles, and at the core and centre of the article, is a layer 14 of large bubbles and very low density. The resulting table does not weigh more than a wooden table, and has the advantage of having been made at an extremely low labour cost, either entirely of aluminium, which is potentially available from clay or entirely of magnesium which can be made from sea water, or of an aluminium-magnesium alloy or of some other metal. Also it has the advantage of great permanence and ruggedness.

Another embodiment of the invention is shown in Figure 3, and in this case a furnace or metal storage tank 20 is maintained under a pressure high enough substantially to repress the cell- or porosity-forming reaction in the metal composition. Agitation is provided by mechanical or electro-magnetic agitation means 21. The tank is connected with a mould 22 by means of a closeable inlet 23. The foaming agent and metal to be foamed are placed in the furnace which is then pressurized with gas introduced at 24 and the components are agitated for good dispersion, under pressure, so that foaming does not take place at that point. The mixture is then fed into the mould, still under pressure, or as an alternative, so rapidly that only a very slight foaming has time to take place before the mixture is introduced into the mould. The pressure is then fully released in the mould and the metal allowed to foam. The temperature balance during this operation is maintained such, that the skin formed on first contact by the hot metal melt with the relatively cold inner wall of the mould, may or may not partially redissolve but does not entirely redissolve by heat conduction from the remaining mass of metal in the inner parts of the mould.

Further embodiments of the invention are shown in the following examples:

Example 1

90% of an alloy composed of 33% magnesium and 67% aluminium melting point 461°C. is intermixed by intense mechanical agitation. with 10% of zirconium hydride, at a temperature of 465°C. This composition, a liquid, is then injected into a stream of molten aluminium metal, in a ratio of 1 part of the mixture to 9 parts aluminium, and agitated with a rotary high speed agitator for rapid commingling and good dispersion of the hydride in the combined metal streams. The metal is then within about 30 seconds, and substantially before the foaming has had time to commence, poured into cold sand moulds.

The resultant articles, in this case laboratory stools having a weight of 3.4 to 3.6 kilos and an apparent specific gravity of 0.4 to 0.425, had a firm outer skin approximately 2 mm. thick, followed by a zone of 3 mm. where limited foaming had taken place, while the inner parts were filled with a metal foam throughout.

Example 2

Titanium hydride powder (1 part) is mixed with 12 parts of aluminium powder and the mixture is enclosed in a thin-walled closely fitting aluminium container. Molten aluminium (200 parts) is placed in a cylindrical mixing vessel and stirred violently with an impeller rotating at 4500 r.p.m. With the aluminium at a temperature of about 675°C. to 680°C. the container containing the powder mixture is tossed or dumped into the molten aluminium and agitation is continued for an additional 10-15 seconds. The impeller is then stopped and withdrawn from the mixture and the mixture is then within about 20 seconds poured into a permanent mould, preheated to 500°C. In the mould the mixture foams and forms an object conforming to the mould shape and having continuous relatively non-porous skin surfaces on all sides, with solid metal on the outside and low density metal foam in the middle and a transition zone near the outer surface wherein the density becomes greater at points further from the centre.

Example 3

Into an aluminium tube having an outside diameter of about 1.5 cm. and an inside diameter of about 1.3 cm. there is placed a mixture of 0.1 kilogram of zirconium hydride powder with 1.2 kilograms of very finely divided aluminium powder, the powder mixture being poured into a series of 3 metre lengths of tubing from one end of each and the tubes being then swaged together, end to end, to form a much longer tube. Molten aluminium is then caused to flow into a mixing vessel fitted with a circular multi-bladed impeller rotating at 7000 revolutions per minute at a rate of about 1 kilogram per minute and the tubing is introduced into the violently stirred aluminium, where it is melted away and the powder mixture dispersed into the aluminium, at a rate of about 0.5 to 0.8 metre per minute. The mixutre thus obtained is allowed to flow over the lip of the mixing vessel into a mould made by bonding a thin layer of sand around a pattern with a suitable resin (known as a "shell-mould") whereupon the mixture foams in the mould to provide an article with smooth substantially non-porous skin surfaces, conforming to the shape of the mould, and metal foam comprising a large number of closed cells extending through most of the interior.

In each of Examples 1, 2 and 3, the non-porous outer skin passes over into the cellular core in a gradual fashion, with an intermediate partly foamed zone between them so that both are integral parts of the same continuous phase and no sharp joints or boundary lines exist within the structure. This contributes to its strength.

The principle disclosed herein, that a metal skin can be obtained by freezing a foamable alloy on contact with a cooler mould before the gas cells have had time to form, and then prevented from entirely re-melting or foaming by the cooling action which is provided by providing mould walls at a suitable temperature, applies to all foamable metal compositions. Therefore, this invention is not restricted to any particular metals. Its use is contemplated for relatively low melting metals, such as aluminium, magnesium, zinc, and lead and alloys thereof and for high melting metals. In this case of lower melting metals, we prefer to use as foaming agents particularly the metal hydrides, such as titanium and zirconium hydrides, but also lithium, lithium-aluminium, and magnesium hydrides, lithium hydride having the advantage that it can be handled in melted form without decomposition, and magnesium hydride having the advantage of leaving a light metal residue after decomposition. Zirconium and titanium hydrides are particularly suitable for use with aluminium, due to their higher decomposition temperatures. If these hydrides are used particles of the metal component of the hydrides may remain undissolved in the melt, depending on its composition.

Other materials which can be used for causing gas formation in foaming metal systems include carbonates such as Na_2CO_3 and $NaHCO_3$, stable hydrates such as chromium oxide hydrate, and decomposable organic materials such as for example phthalocyanine and silicon products.

For higher melting metals, such as the ferrous metals and alloys, nickel, cobalt,

titanium, zirconium, niobium and the like, a convenient way of foaming is to intermix them with a metal which has a boiling point below the melting point of such high melting metal, repress the ebullition by pressure, while mixing, and then suddenly release the pressure. On this release, the low boiling metal, such as for example, zinc, cadmium or lithium, or magnesium, will become a gas, cause copious and rapid cell formation in the high melting metal, and at the same time by evaporation, absorbs enough heat to cause a congelation of the foam of said high melting metal, before the resultant bubbles have had time to burst. Thus results a foamed metal structure in which the metal foam consists of a continuous phase of the high melting metal, and cells containing a vacuum, said cells being coated by the lower boiling auxiliary metal which has condensed on the inner surfaces of each cell. Generally speaking, for application of the method of mixing relatively low boiling metal with a relatively high melting metal, 1150°C. at atmospheric pressure and as the latter metals and alloys melting above 1200°C.

From the standpoint of heat balance in the reaction, it is preferred that the cell forming reaction or process be endothermic, and this is particularly true of the use of lower boiling metals as foam forming agents.

Copper and its alloys occupy an intermediate place between the light metals and the very high melting ones. These can be foamed both by the use of hydrides, under pressure to repress the foaming, and by the use of low boiling metals as explained above.

In effecting the intermixing of the metal at high temperature with the foaming agent, it is desired that no more than from about 10 to about 60 or perhaps 120 seconds pass from the time of adding the foaming agent or cell forming substance, to the time when the mixture is filled into the moulds. This requirement applies where the operation is carried out at atmospheric pressure; when foaming is repressed by high pressure, the mixing time is not critical but may be from 5 to 10 seconds to 5 minutes but then the metal should be brought into the moulds within 50 to 60 seconds.

The temperature of the mould should be at least 50°C. lower than the melting point of the metal being employed, and may be as low as room temperature, and lower. However, the thickness of the skin depends on the difference in temperature between the metal and the inner surface of the mould, as well as on the thermal conductivity of the metal and of the foam, and on the sensitivity of the foaming agent to heat which determines in turn its speed of release. Inasmuch as the particular shape and size of each particular article being cast will determine its cooling rate, as will also the type of mould being used, each particular object will require a somewhat different treatment for best results, as will each particular alloy. Since this invention is applicable to a great number of conditions and materials, it is therefore best not to attempt too close a numerical definition of the conditions; the examples given should enable those skilled in the art to arrive, by extrapolation or interpolation, at the conditions which are best for any particular shape of mould or material to which they may desire to apply this invention. The principle broadly rests on the discovery that surprisingly, it is possible to cast in a single operation even very complex shapes having an altogether different structure in the centre and in the skin, and to obtain firm solid non-porous skin and a highly foamed low density core in a single operation. This is accomplished basically by carrying out the entire operation so rapidly and with such temperature differential between mould surface and metal, that a metal skin is formed on the mould before the metal has had time to start foaming or even while at the same time the metal is foaming in the interior.

This method for the first time makes it possible to cast, in one operation, metal objects which have the same overall weight to volume ratio as wood or plastic objects, together with the high degree of ruggedness, compression and beding strength, and fire resistance of non-hollow metal objects.

WHAT WE CLAIM IS:—

1). The method of casting in one operation, a metal article which may be of complex shape, having a continuous substantially non-porous metal skin and a low density core of the same metal which consists of a large number of closed cells extending through most of the interior of the core, which method comprises the steps of intensively intermixing a molten metal and a substance capable of forming a gas at the melting point of said metal, introducing said mixture substantially before foaming has taken place into a mould, the inner surface of which has a temperature sufficiently low to cause solidification of said metal as a substantially non-porous skin adjacent the inner mould surface and causing to be abstracted or abstracting heat from said mould at such a rate that the said skin is not remelted or foamed.

2). A method as claimed in Claim 1, in which the said substance capable of forming a gas is a metal, having a boiling point below the melting point of the metal

of which the article is composed.

3). A method as claimed in Claim 1, in which the said substance capable of forming a gas is a thermally decomposable chemical composition.

4). A method as claimed in Claim 3, in which the said substance is a metal hydride.

5). A method as claimed in any preceding Claim, in which the time lapse between the intermixing of the gas-forming substance and the metal, and the casting of said metal is less than 120 seconds and the temperature of said mould is at least 50°C. lower than the melting point of said metal.

6). A method as claimed in any preceding Claim, in which the metal of which the article is composed is aluminium, magnesium, zinc, lithium or lead.

7). A method as claimed in any preceding Claim, in which the gas formation during the mixing stage is suppressed by pressure, until casting is ready to take place.

8. A method of casting in one operation, a metal article substantially as hereinbefore described with reference to Figs. 1 and 2 or 3 of the accompanying drawings and/or any one of the foregoing Examples.

9). A metal article having a continuous substantially non-porous metal skin and a low density core of the same metal which consists of a large number of closed cells extending through most of the interior of the core made by the method claimed in any preceding Claim.

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892,934 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

FIG. 1

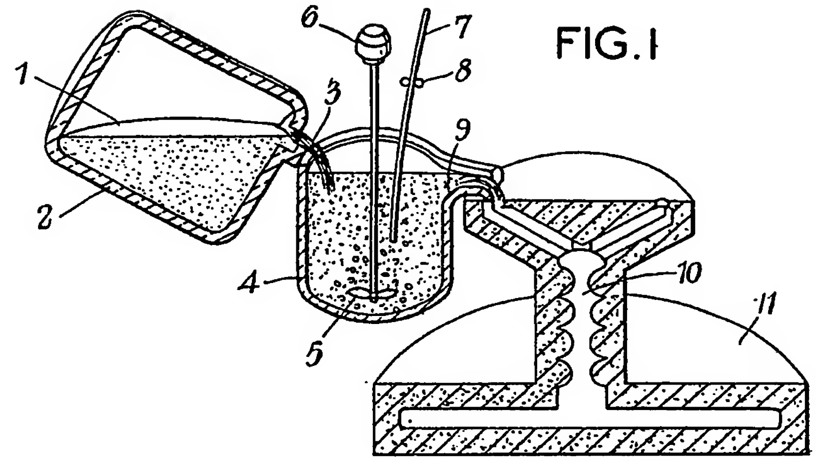

FIG. 3

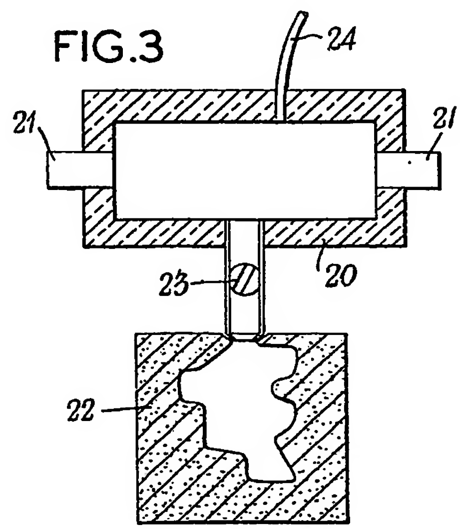

FIG. 2